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EIS IN DIAGNOSTIC OF CATHODIC PROTECTION SYSTEMS

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Summary

Laboratory and field investigation results have been presented of cathodic protection installation elements of an underground steel pipeline by the electrochemical impedance spectroscopy (EIS) technique. Impedance spectra have been presented of the following systems: reference electrode/auxiliary electrodes, pipeline/buried and portable reference electrodes. It has been shown that the discussed technique allows investigation of the technical state of reference electrodes, allowing evaluation of the reliability of potential measurement results of the protected structure. EIS gives information unavailable through traditional DC measurement techniques used in cathodic protection installations. It allows, for example, determination of the resistance of the system: structure/reference electrode. This can be used for estimation of the potential IR component.

Keywords: *cathodic protection, reference electrode, electrochemical impedance spectroscopy*

INTRODUCTION

Potential protection criteria are applied in cathodic protection practice [1]. Most potential criteria are given in different types of normative acts, e.g., American [2] and Polish [3] standards. In most cases it is assumed that the potential of a structure polarized with a DC current should reach a value of -0,85 V versus the copper sulphate electrode. Measurement is performed with a buried reference electrode during the flow of polarising current. Potential criteria raise numerous controversies. The basic drawback is that the potential – as a thermodynamic value – does not give direct information on the corrosion process rate.

Also, one should be sure that in spite of the apparent simplicity of potential measurements, the obtained results can be burdened with significant errors. The most important one is not taking into account of the potential IR component [4,5]. Its presence frequently renders impossible correct determination of electrochemical processes occurring on the metal/electrolyte phase boundary. Hence different techniques are applied, the aim of which is a maximum decrease of the IR component value [6].

During operation of cathodic protection systems on the basis of potential measurements working parameters of the cathodic protection stations (voltage and output current) are corrected, if necessary, so as to obtain the required value and distribution of the protected structure polarization. The correct polarisation degree of a steel structure affects the efficiency of obtained protection, as well as its cost-effectiveness.

From the description presented above it results that stationary buried reference electrodes are a very important element of cathodic protection systems. Correctness of their functioning is evaluated most frequently in practice on the basis of their potential value versus an attested portable reference electrode. Obviously, the result of such a measurement is very unreliable and as a consequence does not protect from erroneous evaluation of cathodic protection system operation. It is therefore essential to apply other methods of reference electrode evaluation, methods giving diagnosis result certainty.

The aim of this work is showing the possibilities of using impedance spectroscopy techniques for inspection of cathodic protection installation elements. The authors do not know literature references of such an application of this technique (it is most frequently used for investigations of coatings). Investigations presented in this work show that EIS allows obtaining of useful information, unavailable through traditional measurement techniques, used in cathodic protection installations.

EXPERIMENTAL METHOD

Investigations were performed in the laboratory and on an over ten-year old cathodic protection installation of a ϕ200 steel pipeline with bituminous insulation.

In the laboratory measurements by the impedance spectroscopy technique were performed with a stationary Schlumberger FRA 1255 setup. The measurement frequency range was from 1 MHz to 0.5 Hz. The amplitude of the perturbation signal ranged from 100 mV to 300 mV. A portable Sycopel Scientific Ltd. generator/analyser setup was used in field measurements. The measurement frequency range was from 10 kHz to 1 Hz. The amplitude of the perturbation signal ranged from 100 mV to 500 mV.

The aim of investigations in the laboratory was:

- Determination of impedance of portable reference electrodes, used later for field measurements in cathodic protection installations,
- Obtaining of initial impedance spectra for comparison of defined two electrode systems in sand, to which field measurement results can be compared.

The following cathodic protection installation systems have been investigated by the EIS technique in the field: pipeline/portable reference electrodes and pipeline/buried stationary reference electrodes. Connections of measurement apparatus to the pipeline and electrodes were performed in control-measurement points of the cathodic protection installation.

RESULTS AND DISCUSSION

Investigations were begun from determination of characteristics of portable copper sulphate reference electrodes. EIS investigations were performed in a three electrode system, in which the copper sulphate electrode was the investigated electrode, the silver electrode was used as reference electrode and a platinised titanium electrode as the auxiliary electrode. Examples of obtained spectra have been presented in Fig. 1. Shapes and locations of impedance spectra in relation to the impedance real component axis depended on the distance between electrodes in investigated systems and on the electrolytic environment (e.g., they result from the dielectric properties of soil [7]). The obtained measurement results did not depend on the amplitude of the perturbation signal, pointing to linearity of the investigated systems. This result is important for further presented investigations. It shows that when a high impedance value is obtained during measurements at low frequencies, it results from the properties of the counter-electrode and not the copper sulphate electrode.

Next the following system was investigated in sand: steel sample/copper sulphate electrode. Examples of obtained spectra are given in Fig. 2. Obtained data show that measurement results do not depend on the amplitude of the perturbation signal. They depend on the spacing between investigated electrodes.

Spectra obtained for a steel sample covered by a paint coating are presented in Fig. 3. It can be seen that the value of the real component of impedance was higher by two orders of magnitude in comparison with the sample with no coating.

Also it was checked which impedance spectra are given by the same system with a coating defect of 1 mm^2 area. Results of investigations are presented in Fig. 4. The value of the real component of impedance was now an order lower. In the impedance spectrum a semicircle can be seen, connected with the electrolyte resistance (for high frequencies) and the coating and steel corrosion processes in the place of coating defect (for low frequencies).

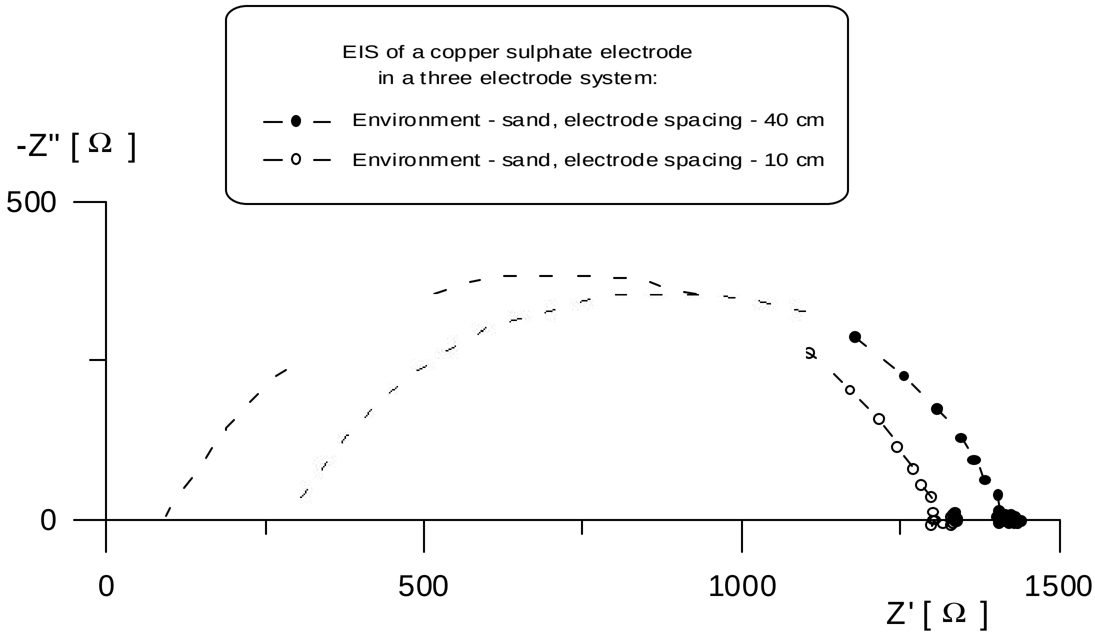

Fig.1. Impedance characteristic of a portable copper sulphate electrode in sand of 1.76 % relative humidity.

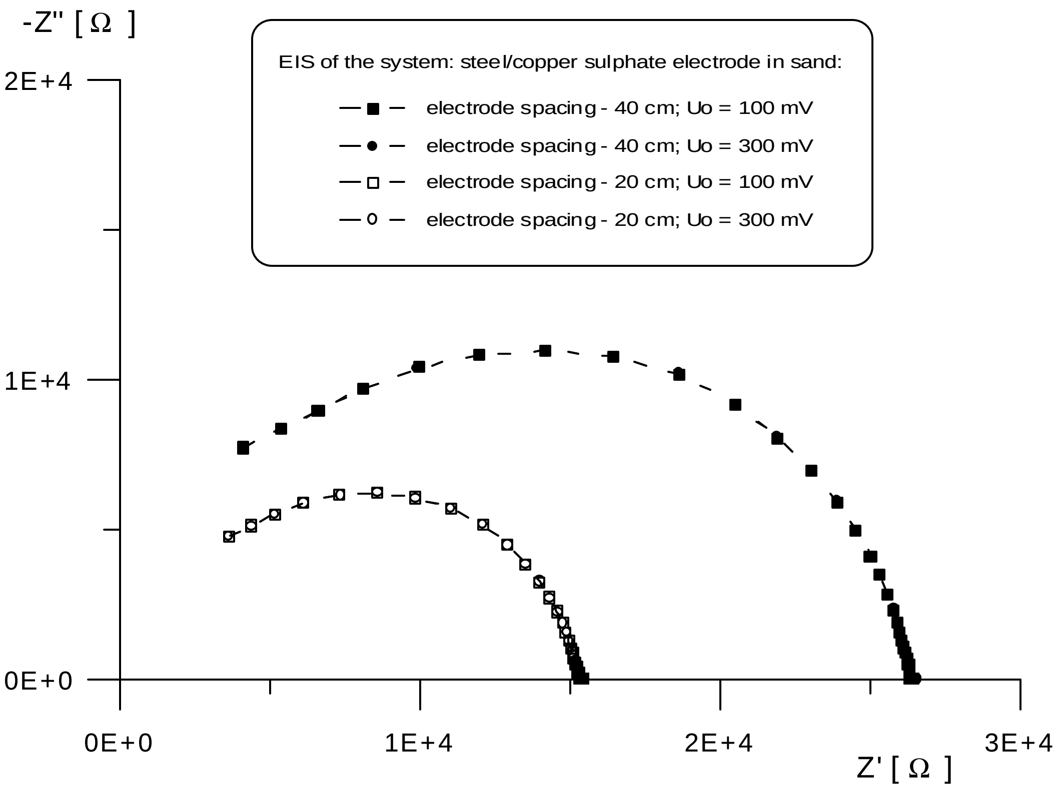

Fig. 2. Impedance spectra of the system steel sample/copper sulphate electrode
in sand of 1.76 % relative humidity.

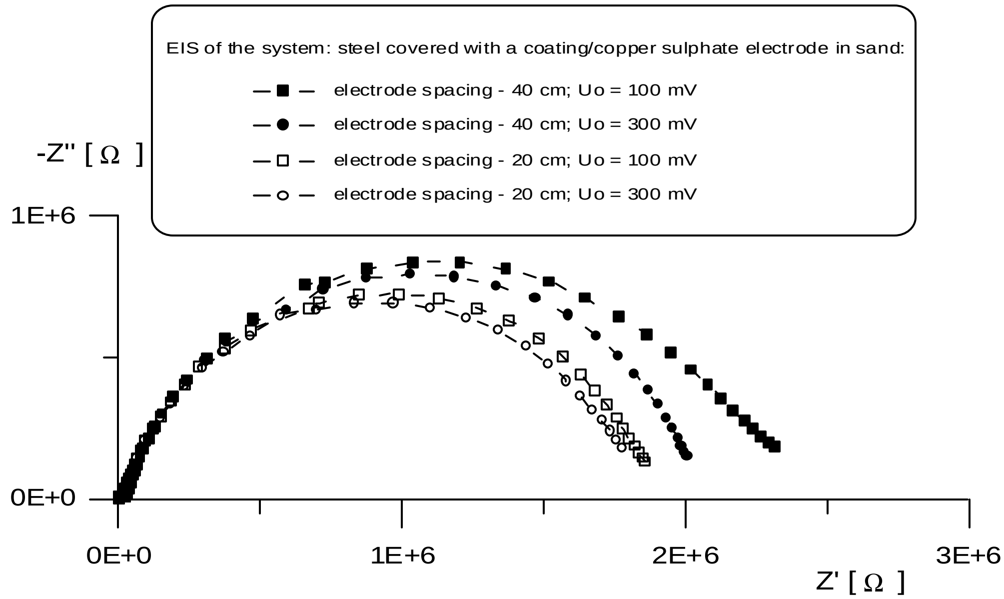

Fig. 3. Impedance spectrum of the system: steel sample covered with a paint coating/ /copper sulphate electrode in sand of 1.76% relative humidity.

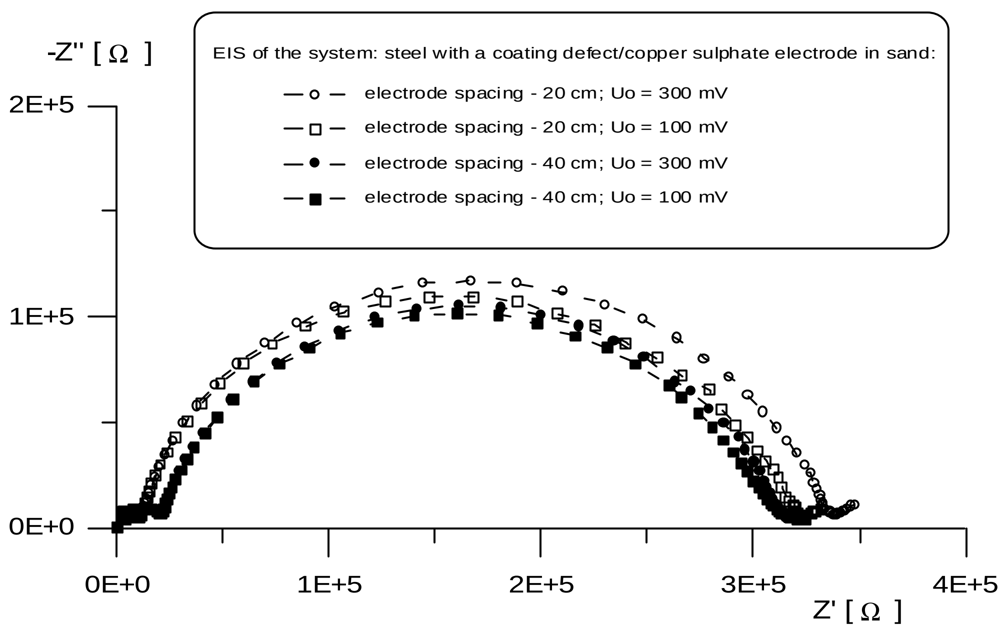

Fig. 4. Impedance spectra of the system as in Fig. 4 with a coating defect of 1 mm^2 area.

Examples of impedance spectra of systems: pipeline/stationary reference electrodes are given in Fig. 5. On the basis of comparison with initial characteristics obtained in laboratory investigations it can be distinctly seen that stationary electrode 3 is completely inefficient and its replacement is essential. This is indicated by a high impedance value (imaginary component) in the whole measurement frequency range and by spectrum shapes obtained for this electrode. Potential measurement results of the pipeline versus this electrode and the attested portable electrode differed by approx. 150 mV.

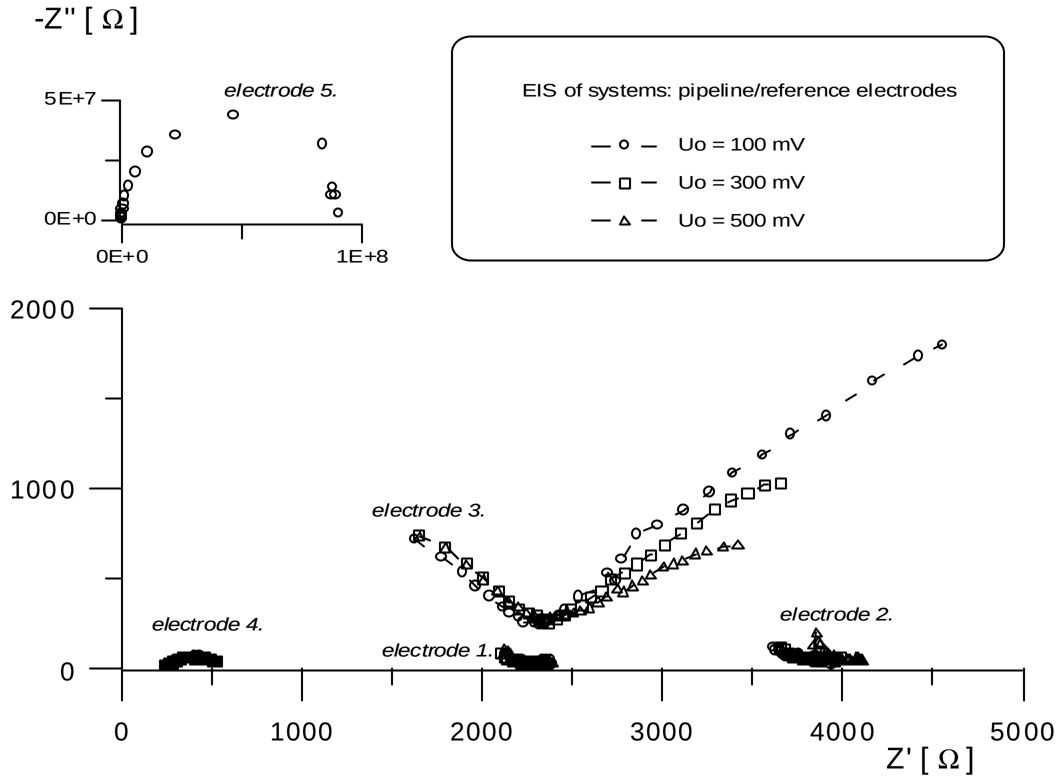

Fig. 5. Impedance spectra of systems: pipeline/reference electrodes.

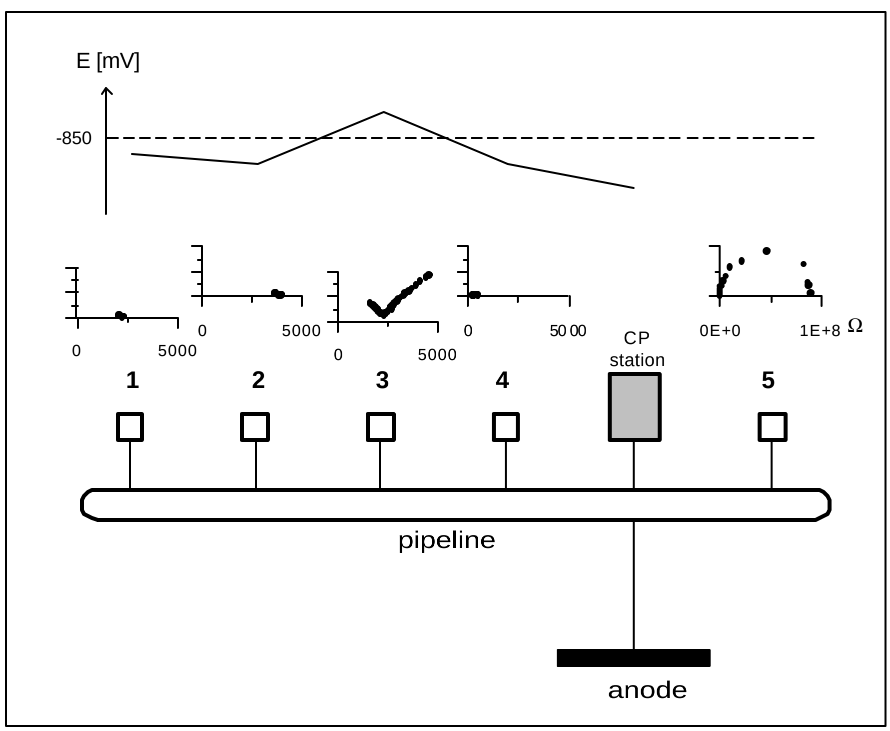

Fig. 6. Potential distribution along the protected pipeline with impedance spectra of the pipeline/reference electrode system.

Measurement data obtained for electrode 5 indicate damage of the electric cable from the electrode or pipeline in this control-measurement point. From comparison of the remaining spectra presented in Fig. 5 it results that resistances of the systems pipeline/investigated reference electrodes significantly differ and range from approx. 500 Ω to approx. 4 kΩ. These data suggest that potential measurement results versus electrode 4 are burdened with a much smaller IR component error than in the case of electrode 1 and the more so of electrode 2. This can also show that after over ten years of operation electrode 4 is most efficient. This is an indication concerning supervision of the operation of the investigated protective installation: potential measurement results obtained versus electrodes 1 and 2 should be approached with higher caution than those versus electrode 4.

The potential distribution along the protected gas pipeline (measured in control-measurement points) together with impedance spectra obtained for pipeline/electrode systems have been presented in Fig. 6. Impedance spectroscopy allowed determination, amongst others, that measurement results versus electrode 3 do not indicate lack of protection of the gas pipeline in this place, but result from the defect of this electrode.

SUMMARY

Performed investigations have pointed to the possibility of using the electrochemical impedance spectroscopy technique for inspection of reference electrodes in cathodic protection installations. The obtained impedance spectra of pipeline/reference electrode systems allow determination of the technical state of electrodes. Hence, protected structure potential measurements obtained during supervision of the operation of cathodic protection installations can be made more reliable.

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